

Spaceborne imaging Radar-C: An Advanced imaging Radar Studied the Earth

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After nearly 10 years of hiatus, the U.S. launched the most sophisticated imaging radar ever on-board the space shuttle Endeavor twice within a year as part of NASA's Mission to Planet Earth Program. The Space Radar Laboratory (SRL), consisted of the NASA/JPL Spaceborne imaging Radar (SIR-C), the German/Italian X-Band Synthetic Aperture Radar (X-SAR), and the NASA/University of Maryland Measuring Air Pollution from Space (MAPS). SRL was flown as the primary payload for two 11-day missions, STS-59 in April, and STS-68 in October of 1994. SRL had near flawless performance in each mission allowing for over 110 tera-bits of radar data to be collected in support of 52 science investigations involving 12 countries. Survey image products were available within 3 months following each mission. High resolution, calibrated images will be processed over a 2 year period as required to support science investigators. Both SIR-C and X-SAR belong to the class of radar called synthetic aperture radars (SAR's) which operate in the microwave regime and are capable of generating high resolution images. Operating in the portion of electromagnetic spectrum that is known for immunity to blockage or perturbation from microparticles such as clouds and rain, SAR offers all-weather operations for near-surface imaging. Like most radar systems, SAR provides its own illumination, enabling 24-hour operation regardless of solar illumination. In addition, SAR imagery provides unique measurements relating surface feature interaction with microwaves, which is complementary to what other sensors operating in other portions of the spectrum can provide. With these capabilities, SAR systems have been a tool of interest for many earth science disciplines, as demonstrated by the variety of disciplines represented by the SIR-C/X-SAR science team. The primary disciplines of team members are ecology, geology, hydrology, and oceanography, augmented by electromagnetic theory and calibration technique investigation.

SIR-C is the third generation of SAR's aboard the space shuttle. Its predecessors, SIR-A and SIR-B (flown on STS-2, 1981, and STS-41 G, 1984, respectively), were direct descendants from the first spaceborne remote sensing SAR flown on SEASAT in 1978. With experience and lessons learned from its predecessors and with the advance of new technologies, SIR-C/X-SAR is the most powerful and versatile radar of its genre. The multifrequency, multipolarization versatility is what makes SIR-C/X-SAR stand out among the spaceborne SAR systems of the past (e.g. U.S. SEASAT SAR, SIR-A, SIR-B), the present (European ERS-1 and Japanese JERS-1), and in the near future (Canadian RadarSAT). Although primarily the result of various requirements demanded by the diverse fields of investigation, SIR-C's versatility also expresses the desire to demonstrate SAR technology in its

many engineering experimental modes. Among these special operation modes are wide-swath mapping scanning SAR and high resolution spot-mapping SAR, which are being studied for future SAR missions,

Imaged areas respond, or back-scatter energy, differently for different frequencies, SIR-C/X-SAR operates in three frequencies: L-band at 23.5 cm wavelength, C-band at 5.8 cm wavelength and X-band at 3 cm wavelength. Operation is either simultaneous or independent, For a given extended target, the scattering mechanism is a mixture of surface scattering and volume scattering, and the dominance of one over another is a strong function of wavelength. In general surface scattering is more prominent at shorter wavelengths and volume scattering is more prominent at longer wavelengths enabling the longer wavelength to penetrate or see-through the surface for some targets. Even for surface scattering, the scale of surface features, e.g. roughness, will enhance scattering in one wavelength over another. The three frequency capability of SIR-C/X-SAR allows the scientists to exploit the scattering phenomenon manifested in these three frequencies for target characterization and classification. During the missions, SIR-C/X-SAR operated simultaneously to acquire data from the majority of sites, making three frequency comparison possible,

The balance of data covered herein will focus on the NASA/JPL imaging radar, SIR-C.

For L and C-band, SIR-C can acquire scattering data to fully describe the scattering from a target. The reflectivity of a target is a strong function of polarization. In general, four complex quantities which constitute the four elements of the scattering matrix are needed to characterize the target reflectivity. The polarization of the illumination can be decomposed into a chosen set of two independent polarization bases, e.g. vertical and horizontal pair or right-hand circular and left-circular pair. This is also true for the polarization of the reflected signals. Although the usefulness of this polarization diversity has long been recognized, the utilization of full polarization was not realized until after the first airborne SAR bearing the capability became operational in 1985. SIR-C is the first spaceborne SAR equipped with this capability. Pulses of vertical polarization and horizontal polarization can be transmitted alternately, and the returned echoes due to each transmitted polarization are received in both vertical and horizontal polarizations. More important, once these four polarimetric measurements are obtained and system-induced bias among them removed, reflectivity arising from any polarizations can be synthesized. A scientist can select or synthesize one or more polarizations, or the characteristic variation among polarizations, to enhance the ability to discriminate and classify various types of targets of interest.

The SIR-C antenna consists of two antennas, one for each frequency. Since the two antennas are of similar architecture, the C-band antenna will be used as an example. Measuring 12.05 m (along-track) by 0.75 m (cross-track), the C-band antenna is a dual-polarization phased array antenna consisting of 18 by 18 dual-polarization elements, each containing a pair of phase-shifters, one for each polarization. By controlling the values of the phase-shifters, the antenna beams can be pointed electronically to $\pm 10^\circ$ along-track and $\pm 23^\circ$ cross-track from the mechanical boresight. The quick beam switching capability enables SIR-C to image two closely spaced target sites at very different look angles in succession. It also made available other interesting operational modes. For a selected beam width, the beam can be switched cyclically to scan in the cross-track dimension over a swath four times wider than that a single beam would cover in one SIR-C experimental mode called ScanSAR mode. Another mode is to scan the antenna beam in along track dimension by pointing a beam toward a selected target for the 2° scanning limitation, thus considerably increasing the time over which a target would normally be exposed for 0.25° without scanning. This spot-light mode operation improves the resolution along track, as it lengthens the target exposure time. By manipulating the phase shifter values, the SIR-C antenna beam width can be varied from 5.2° to 18.4° in cross-track. This allows more flexibility in trading off performance vs. coverage.

There are hundreds of transmitter/receiver modules (T/R's) embedded in each SIR-C antenna. The architecture of this active array is conducive to improved sensitivity, to increased transmit power and to lower overall noise contribution. In addition, the distributed layout and large number of T/R's allow failure of some T/R's without significantly degrading the radar performance. Some T/R's did fail during the mission. These failures were uncovered through a special engineering sequence exercised frequently during the mission. Once detected, compensation is easily applied during calibrated image processing.

Operations of the SAR requires a platform, which is the shuttle in this case, accompanied by the entire shuttle infrastructure for payload integration and operations. Tools are needed to plan the data takes prior to the missions and to control the radar to set up the proper radar parameters for a specific site during the mission. The SIR-C mission planning and operations system provides this utility and more. It interfaces with the shuttle mission control center to receive orbit and radar telemetry. It delivers radar commands back to mission control and planning information to its X-SAR counterpart. For most of the mission time SIR-C and X-SAR were collecting data from the same target sites simultaneously and operating synchronously. The SIR-C-related crew activities were planned, revised and uplinked during the missions. These activities included special crew observation, special shuttle maneuvering, recorder maintenance and tape changes. It also contained data downlink events for ground data recording. All SIR-C mission relevant

information was archived by the mission operations system, most of it in a large database. Mission planning inputs, radar commands, and radar telemetry (at a rate of 1890 bytes per second) were among those archived for future usage. Problems encountered during the missions were also documented for later reference.

It is no trivial matter to generate an optimal mission timeline within the known constraints. For each SIR-C flight, some 700 science data takes were attained by commanding to a specific configuration carefully selected by the science team. The mission operations system provides the utilities for scientists and planners to optimize the timeline through many models and the complicated inter-dependent relationship among them. The pertinent information from these models was presented to the planners for proper prioritization and trade-off, and the resultant timeline was presented to the entire operations team for visualizing upcoming events. During the missions, the parameters of models were updated and actual measurements were constantly fed to the models to revise future predictions. New target-of-opportunity sites were requested by investigators and incorporated into this process.

Raw SAR data, as captured by the radar, has the appearance of Gaussian noise with the exception of strong point-like targets. Images suitable for scientific investigation emerge from the raw data only after computation intensive, and time consuming processing. The SIR-C processor is the last, but not the least, of the three segments in the flow of the SIR-C program, the other two being the flight radar instrument and mission operations system. The processor relies on the ancillary information delivered by the mission operations system as well as that embedded in the radar data to convert the noise-like radar data into quality imagery. It applies correction factors to remove known systematic biases, e.g. antenna pattern and system imbalance, to provide quantitatively calibrated images. Given the complexity of the radar, it is not surprising that the processor has to be as capable, in addition to image generation, the SIR-C processor system also provides utilities to handle processing requests and quick dissemination of final products,

The quality of radar images is usually quantified by: the sharpness of a point-target response attainable in the image; by the great simplification of the radar as a linear system, and by the contamination of undesired signals such as sidelobes, ambiguities and noise, all of which detract from image interpretation. As nature would have it, sharper point-target response can be achieved at high level of contamination. For a SAR, the sharpness of the point-target response in the along-track dimension is highly dependent on the platform attitude control and how the orbit information is being used by the processor. For the SIR-C mission, the shuttle attitude control performed remarkably well. Vernier jets were constantly fired to control the attitude to better than requirements, which ironically rendered some sophisticated

algorithms prepared by the processor unnecessary. The high degree of coherence required of a SAR with a wavelength comparable to the dimension of homogeneous targets on the ground, creates speckle in the images of such targets. Having a highly grainy appearance, the radar speckle, which closely relates to laser speckle physically and mathematically, render the images less interpretable but can be suppressed by combining independent images of the same scene at the cost of resolution. The SIR-C processor implemented algorithms which strike a balance between these trades. Image products are available in several formats, ranging from low resolution strip survey images to high resolution complex frame images,

Perhaps the most important aspect of SIR-C products is that the images are calibrated. Calibration is a process by which the residual systematic biases in the measurements are determined and removed in the final products, which for SIR-C are the radar imagery. Only when these systematic biases are removed, can more quantitative and cross-sensor comparative studies be performed. For SIR-C, calibration requirements were levied in three categories: radiometric, polarimetric, and geometric calibrations, and each of these categories can be further divided into short-term within an image or long-term over many data takes. SAR calibration has advanced significantly during the period SIR-C was being implemented, in particular in the polarimetric calibration areas; after all, the advent of a full polarimetric SAR is only a relatively recent event. Since SIR-C provides data in different polarizations and frequencies, the biases among these channels have to be removed, in magnitude, phase, as well as pixel location, so that the images from different frequencies and polarizations are registered and can be compared between frequencies and synthesized to any desired polarizations. The SIR-C processor obtained the calibration information from two sources: from the pre-mission radar test data and in-flight radar data, known as internal calibration, and from the known characteristics of targets on the ground which is commonly known as external calibration. The injection of calibration signals by the radar into returned signals and antenna modeling from pre-mission testing are generally considered internal calibration, whereas the deployment of targets with known signatures and radar performance monitoring equipment at carefully surveyed locations for selected sites are external calibration. It was no small feat that a fully calibrated dual-frequency polarimetric image set was released only several days into the first mission. It is even more significant that SIR-C processor is presently delivering calibrated images as standard products.

SIR-C started with a set of science requirements and a science plan in 1985. For two brief 11-day periods in April and October, 1994, it had met the challenging requirements and beyond. It was a tremendous and exciting demonstration that a radar of this complexity and versatility can be built with all the companion elements to support its planning, operations and product generation. SIR-C had collected an arguably "ultimate" set of data which are

simultaneous multi frequency and multipolarization over two different seasons in a single calendar year. Complemented by the concerted measurements conducted on the ground during the missions, scientists of various disciplines have at their disposal the best and complete set of radar data to compare with their theories and models and refine their algorithms. The interferometry experiment conducted during the second flight clearly demonstrated that global high resolution topographic maps are within the reach of current SAR technology. The usefulness of various experimental modes and specific engineering designs will be evaluated. Undoubtedly, more exciting results will be forthcoming in the years to come -- for us to better understand what applications can best be served with a further refined SAR in the future.

Currently the Office of the Mission to Planet Earth of the National Aeronautics and Space Administration has underway a review by the National Research Council of the value of SAR to the science community. The outcome of this study will provide a major input to NASA's long term plan for the U.S. civilian SAR program. Options under consideration include additional flights of SIR-C/X-SAR for additional seasonal coverage or with an emphasis on interferometry, conversion of the SIR-C /X-SAR into an independent, free flying spacecraft, the development of an interferometric SAR system focused on the production of a high resolution (30 meter), high accuracy (2 to 5 meter) global Digital Elevation Model (DEM), and the development, with the participation of foreign partners, of a SIR-C/X-SAR free flyer system utilizing modern technologies to light weight and miniaturize components,

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Captions and Table

[Figure Caption]

SIR-C imaging scenario.

Flying at a nominal altitude of 225 km with nominal velocity of 7.5 km/sec on-board the space shuttle, SIR-C points its antenna away from nadir and perpendicular to the flight track to image target areas on the ground. This image scenario creates an image swath in the along track dimension with the swath width in the cross-track dimension limited by the footprint of the SIR-C antenna beam. SIR-C can electronically steer its antenna to look at targets between 20° to 60° from nadir and provide different antenna beam width to result in 15 to 90 km swath coverage. During data acquisition, SIR-C sent narrow microwave pulses toward the target repetitively and the returned signals of these pulses were processed after the flight to generate high resolution images.

[Photo Caption]

Taken with a hand-held 70-mm camera through the space shuttle's aft flight deck window during the April flight, this photograph shows the payload bay of the Endeavour with an area of the Pacific Ocean northeast of Hawaii in the background. The SIR-C antenna, with its large triangular support structure and flat antenna panels, almost fills the payload bay. The larger panels in the center constitute the L-band antenna and the smaller panels toward the starboard side of the shuttle are the C-band antenna. Both L-band and C-band antennas are electronically steerable phased arrays. The tilting of the X-band antenna, located at the port side of the shuttle, is controlled mechanically. The bulk of the remaining radar electronics are located under the antenna structure and mounted on a cargo pallet, which are invisible from this perspective. The recorders are located inside the crew cabin.

[Radar image Caption]

Mt. Rainier, Washington.

The majestic Mt. Rainier was captured by SIR-C during its second flight in this 59 km by 60 km image. The image is a composite of simultaneous L- and C-band images of selected polarizations; red and green represent L-band horizontal and vertically polarized backscatter components, respectively, when the site was illuminated with horizontally polarized pulses, blue indicates the C-band vertically polarized received component due to horizontally polarized illumination. In addition to highlighting topographic slopes of the area, this particular color rendition exploits the sensitivity of ground features in response to different radar frequencies and polarizations to bring out features of interest to scientists. For example, forested regions are in pale green color; clear cuts and bare ground are bluish or purple; ice is dark green and white. Radar images allow scientists can be used to study the volcanic structure and the surrounding regions. In addition, by manipulating polarization and frequency parameters, SIR-C images allow scientists to monitor the recovery of forested lands from natural disasters, or deforestation and reforestation activities.

[Radar image Caption]

Changes surrounding Mt. Pinatubo, the Philippines.

Acquired in April and October, 1994, these two composite SIR-C images of areas surrounding Mt. Pinatubo show significant changes in the intervening five-month period. The same pseudo-color scheme was applied to each image to combine J,- and C-band images of selected polarizations. Red on the high slopes shows the distribution of the volcano ash deposited during the 1991 eruption. The dark drainage radiating away from the summit indicates smooth mudflows, which even three years after the eruption continue to flood the river valleys after heavy rain. Comparing the two images shows that significant changes have occurred along the Pasig-Potrero rivers (the dark area in the lower right of the images) and the surrounding areas due to the monsoon season between two SIR-C flights. Radar imaging is particularly useful, due to its insensitivity to weather disturbances and solar illumination, during the monsoon season when the mudflows form. Combining frequency and polarization, radar images can bring out features relevant to mudflows which are more difficult to identify by other sensors. Frequent imaging of these mudflows will allow scientists to better predict when they are likely to begin flowing again and which communities might be at risk.

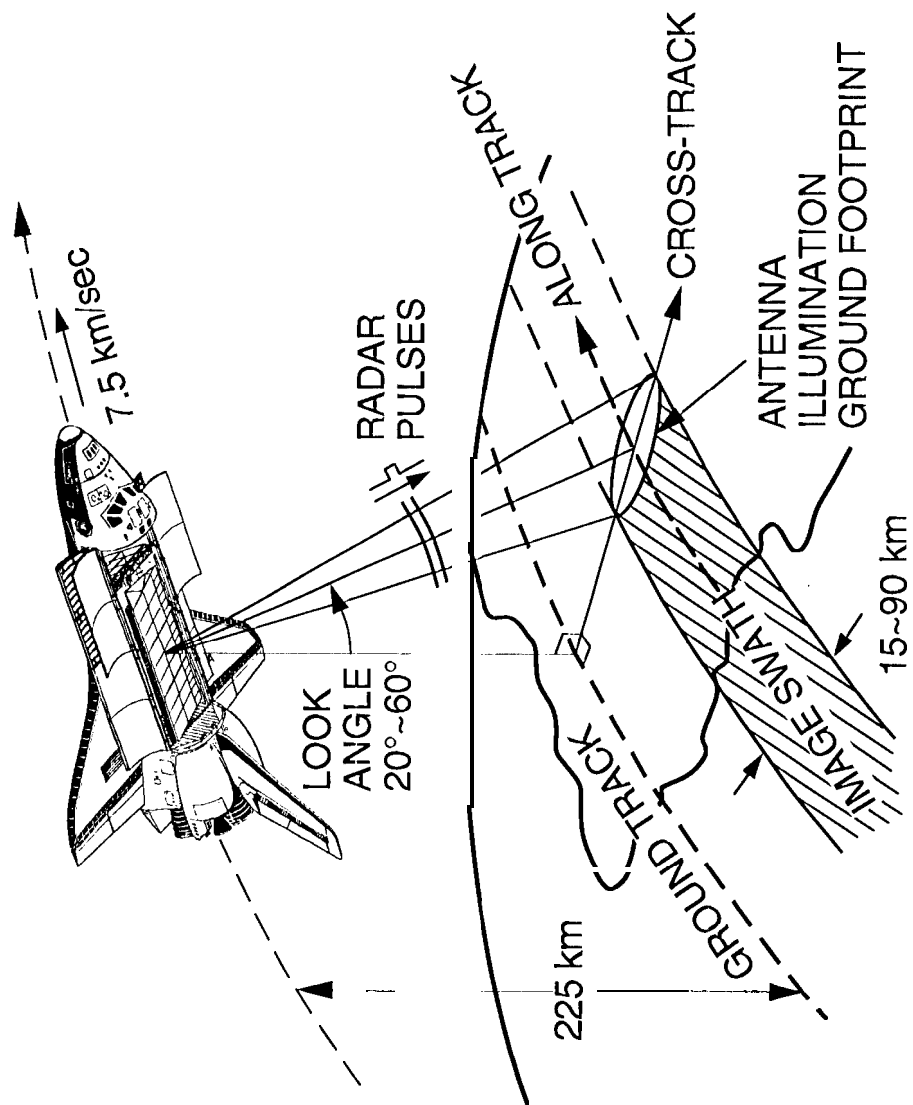
[Radar image Caption]

Topographic map of Long Valley, California.

The topographic contours on top of the radar image were derived from a pair of SIR-C L-band images, one obtained during the first flight and the other during the second mission. During the second flight the shuttle and the radar were carefully controlled to repeat nearly the same imaging geometry to the first flight except for a slight difference in look angle. The color and the contours (at 50 m intervals) shown in this image are elevations derived interferometrically from the phase information of these two images, while the brightness is determined by the radar backscatter. The height accuracy of this digital elevation model is estimated to be 20 m over an area of 50 km by 50 km near Long Valley, California. The interferometry experiments conducted during the SIR-C second flight demonstrated the feasibility of using spaceborne imaging radars to obtain elevation information of the target site. The interferometric data sets acquired by SIR-C will allow better understanding of system trade-off and limitations of this technique, leading to a future radar mission dedicated to the generation of high resolution global topographic maps, which at present are available on local and regional scales and of inhomogeneous quality.

[Table]
Nominal SIR-C parameters

Mission parameters		
orbit altitude	225 km	
Orbit inclination	57°	
Ground velocity	7,500 m /sec	
Antenna boresight	400 from nadir	
instrument mass	11,000 kg	
DC power consumption	3,000 to 8,500 watts	
Mission duration	10+1 day each flight	
Radar parameters		
	L-band	C-band
Wavelength	23.5 cm	5.8 cm
Transmit peak power	5,250 watts	1,350 watts
Antenna size	12.02 m by 2.95 m	12.05 m by 0.75 m
Antenna gain	37.8 dBi	43.8 dBi
Along track beam width	1.05°	0.25°
Detectable target backscatter	>-50 dB	>-35 dB
Dynamic range	20 dB (distributed); 50 dB (point targets)	
Transmit waveform	Linearly frequency modulated pulse	
Transmit pulse width	33.8, 16.9, 8.44 μsec (selectable)	
Transmit pulse bandwidth	10, 20, 40 MHz (selectable)	
Transmit pulse rate	1240 to 2160 Hz (16 selectable)	
Transmit/receive polarization	Horizontal and/or vertical	
Ant. cross-track beam width	5.2° to 18.4° (8 selectable)	
Ant. cross-track beam steering	±20° from boresight	
Ant. along-track beam steering	±1° from boresight	
Data digitization rate	45 MHz (at 8 bits/sample)	
Data format (per sample)	4 bits, 8 bits, and 4 bits adaptive quantization	
Data recording rate	180 Mbits/sec	
Standard image product parameters		
Cross-track swath width	15 to 90 km	
Resolution	25 m by 25 m	
Absolute calibration	<±2.3 dB	
Cross-swath calibration	<±1.0 dB	
Polarization amp. imbalance	<±0.7 dB	
Polarization phase imbalance	<6°	





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PHOTO CAPTION

P-14703
October 3, 1994
Mount Rainier, Washington
L, C bands

This is a radar image of Mount Rainier in Washington state. The volcano last erupted about 150 years ago and numerous large floods and debris flows have originated on its slopes during the last century. Today the volcano is heavily mantled with glaciers and snowfields. More than 100,000 people live on young volcanic mudflows less than 10,000 years old and, consequently, are within the range of future, devastating mudslides. This image was acquired by the Synthetic Aperture Radar (SIR-C/X-SAR) aboard the space shuttle Endeavour on its 20th orbit on October 1, 1994. The area shown in the image is approximately 59 kilometers by 60 kilometers (36.5 miles by 37 miles). North is toward the top left of the image, which was composed by assigning red and green colors to the L-band, horizontally transmitted and vertically received, and the L-band, horizontally transmitted and vertically received. Blue indicates the C-band, horizontally transmitted and vertically received. In addition to highlighting topographic slopes facing the space shuttle, SIR-C records rugged areas as brighter and smooth areas as darker. The scene was illuminated by the shuttle's radar from the northwest so that northwest-facing slopes are brighter and southeast-facing slopes are dark. Forested regions are pale green in color; clear cuts and bare ground are bluish or purple; ice is dark green and white. The round cone at the center of the image is the 14,435-foot (4,399-meter) active volcano, Mount Rainier. On the lower slopes is a zone of rock ridged and rubble (purple to reddish) above coniferous forests (in yellow/green). The western boundary of Mount Rainier National Park is seen as a transition from protected, old-growth forest to heavily logged private land, a mosaic of recent clear cuts (bright purple/blue) and partially regrown timber plantations (pale blue). The prominent river seen curving away from the mountain at the top of the image (to the northwest) is the Skagit River, and the river leaving the mountain at the bottom right of the image (south) is the Nisqually River, which flows out of the Nisqually glacier on the mountain. The river leaving to the left of the mountain is the Carbon River, leading west and north toward heavily populated regions near Tacoma. The dark patch at the top right of the image is Bumping Lake. Other dark areas seen to the right of ridges throughout the image are radar shadow zones. Radar images can be used to study the volcanic structure and the surrounding regions with linear rock boundaries and faults. In addition, the recovery of forested lands from natural disasters and the success of reforestation programs can also be monitored. Ultimately this data may be used to study the advance and retreat of glaciers and other forces of global change.

Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar (SIR-C/X-SAR) is part of NASA's Mission to Planet Earth. The radars illuminate Earth with microwaves, allowing detailed observations at any time, regardless of weather or sunlight conditions. SIR-C/X-SAR uses three microwave wavelengths: the L-band (24 cm), the C-band (6 cm) and the X-band (3 cm). The multi-frequency data will be used by the international scientific community to better understand the global environment and how it is changing. The SIR-C/X-SAR data, complemented by aircraft and ground studies, will give scientists clearer insights into those environmental changes which are caused by nature and those changes which are induced by human activity. SIR-C was developed by NASA's Jet Propulsion Laboratory. X-SAR was developed by the Dornier and Alenia Spazio companies for the German space agency, Deutsche Agentur fuer Raumfahrtangelegenheiten (DARA), and the Italian space agency, Agenzia Spaziale Italiana (ASI), with the Deutsche Forschungsanstalt fuer Luft und Raumfahrt e.v. (DLR), the major partner in science, operations and data processing of X-SAR.



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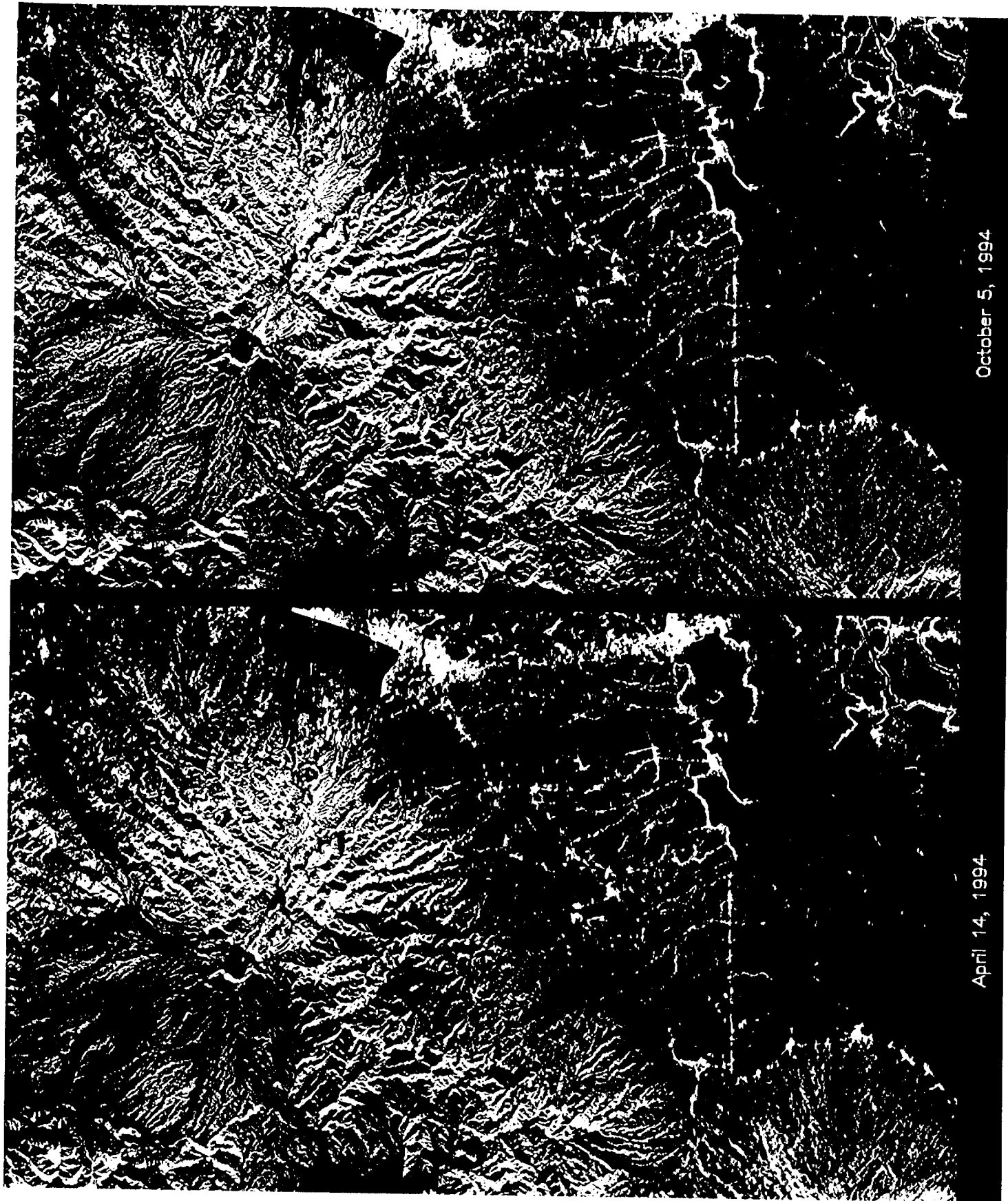
PIIO10 CAPTION

P-44729
October 7, 1994
Mount Pinatubo, Philippines
L, C bands

These are color composite radar images showing the area around Mount Pinatubo in the Philippines. The images were acquired by the Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar (SIR-C/X-SAR) aboard the space shuttle Endeavour on April 14, 1994 (left image) and October 5, 1994 (right image). The images are centered at about 15 degrees north latitude and 120.5 degrees east longitude. Both images were obtained with the same viewing geometry. The color composites were made by displaying the L-band (horizontally transmitted and received) in red, the L-band (horizontally transmitted and vertically received) in green, and the C-band (horizontally transmitted and vertically received) in blue. The area shown is approximately 40 kilometers by 65 kilometers (25 miles by 40 miles). The main volcanic crater on Mount Pinatubo produced by the June 1991 eruptions and the steep slopes on the upper flanks of the volcano are easily seen in these images. Red on the high slopes shows the distribution of the ash deposited during the 1991 eruption, which appears red because of the low cross-polarized radar returns at C and L bands. The dark drainages radiating away from the summit are the smooth mudflows, which even three years after the eruptions continue to flood the river valleys after heavy rain. Comparing the two images shows that significant changes have occurred in the intervening five months along the Pasig-Potrero rivers (the dark area in the lower right of the images). Mudflows, called "lahars," that occurred during the 1994 monsoon season filled the river valleys, allowing the lahars to spread over the surrounding countryside. Three weeks before the second image was obtained, devastating lahars more than doubled the area affected in the Pasig-Potrero rivers, which is clearly visible as the increase in dark area on the lower right of the images. Migration of deposition to the east (right) has affected many communities. Newly affected areas included the community of Bacolor, Pampanga, where thousands of homes were buried in meters of hot mud and rock as 80,000 people fled the lahar-stricken area. Scientists are closely monitoring the westward migration (toward the left in this image) of the lahars as the Pasig-Potrero rivers seek to join with the Porac River, an area that has not seen laharic activity since the eruption. This could be devastating because the Pasig-Potrero rivers might be permanently redirected to lower elevations along the Pomoc River where communities are located. Ground saturation with water during the rainy season reveals inactive channels that were dry in the April image. A small lake has turned into a pond in the lower reaches of the Potrero River because the channels are full of lahar deposits and surface runoff has nowhere to flow. Changes in the degree of erosion in ash and pumice deposits from the 1991 eruption can also be seen in the channels that deliver the mudflow material to the Pasig-Potrero rivers. The 1991 Mount Pinatubo eruption is well known for its near-global effects on the climate. One of short-term climate due to the large amount of sulfur dioxide that was injected into the upper atmosphere. Locally, however, the effects will most likely continue to impact surrounding areas for as long as the next 10 to 15 years. Mudflows, quite certainly, will continue to pose severe hazards to adjacent areas. Radar observations like those obtained by SIR-C/X-SAR will play a key role in monitoring these changes because of the radar's ability to see in daylight or darkness and even in the worst weather conditions. Radar imaging will be particularly useful, for example, during the monsoon season, when the lahars form. Frequent imaging of these lahar fields will allow scientists to better predict when they are likely to begin flowing again and which communities might be at risk.

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P-44729



April 14, 1994

October 5, 1994

SPACEBORNE IMAGING RADAR-C/
X-BAND SYNTHETIC APERTURE RADAR
(SIR-C/X-SAR)

PIIOTO CAPTION

P-44744
October 10, 1994
Long Valley, California
L band

An area near Long Valley, California, was mapped by the Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar aboard the space shuttle Endeavor on April 13, 1994, during the first flight of the radar instrument, and on October 4, 1994, during the second flight of the radar instrument. The orbital configurations of the two data sets were ideal for **interferometric** combination -- that is overlaying the data from one image onto a second image of the same area to create an elevation map and obtain estimates of topography. Once the topography is known, any radar-induced distortions can be removed and the radar data can be geometrically projected directly onto a standard map grid for use in a geographical information system. The 50 kilometer by 50 kilometer (31 miles by 31 miles) map shown here is entirely derived from SIR-C L-band radar (horizontally transmitted and received) results. The color shown in this image is produced from the **interferometrically** determined elevations, while the brightness is determined by the radar **backscatter**. The map is in Universal Transverse **Mecator (UTM)** coordinates. Elevation contour lines are shown every 50 meters (164 feet). **Crowley** Lake is the dark feature near the south edge of the map. The Adobe Valley in the north and the Long Valley in the south are separated by the Glass Mountain Ridge, which runs through the center of the image. The height accuracy of the **interferometrically** derived digital elevation model is estimated to be 20 meters (66 fret) in this image.

Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar (**SIR-C/X-SAR**) is part of NASA's Mission to Planet Earth. The radars illuminate **Earth** with microwaves, allowing detailed observations at any time, regardless of weather or sunlight conditions. **SIR-C/X-SAR** uses three microwave wavelengths: L-band (24 cm), C-band (6 cm) and X-band (3 cm). The multi-frequency data will be used by the international scientific community to better understand the global environment and how it is changing. The **SIR-C/X-SAR** data, complemented by aircraft and ground studies, will give scientists clearer insights into those environmental changes which are caused by nature and those changes which are induced by human activity. SIR-C was developed by NASA's Jet Propulsion Laboratory. **X-SAR** was developed by the Dornier and **Alenia Spazio** companies for the German space agency, **Deutsche Agentur fuer Raumfahrtangelegenheiten (DARA)**, and the Italian space agency, **Agenzia Spaziale Italiana (ASI)**, with the **Deutsche Forschungsanstalt fuer Luft und Raumfahrt e. V.(DLR)**, the major partner in science, operations and data processing of **X-SAR**.

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